

A Web 2.0 and OGC Standards Enabled Sensor Web Architecture for Global Earth Observing System of Systems

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Abstract—This paper will describe the progress of a 3 year research award from the NASA Earth Science Technology Office (ESTO) that began October 1, 2006, in response to a NASA Announcement of Research Opportunity on the topic of sensor webs. The key goal of this research is to prototype an interoperable sensor architecture that will enable interoperability between a heterogeneous set of space-based, Unmanned Aerial System (UAS)-based and ground based sensors. Among the key capabilities being pursued is the ability to automatically discover and task the sensors via the Internet and to automatically discover and assemble the necessary science processing algorithms into workflows in order to transform the sensor data into valuable science products. Our first set of sensor web demonstrations will prototype science products useful in managing wildfires and will use such assets as the Earth Observing 1 spacecraft, managed out of NASA/GSFC, a UAS-based instrument, managed out of Ames and some automated ground weather stations, managed by the Forest Service. Also, we are collaborating with some of the other ESTO awardees to expand this demonstration and create synergy between our research efforts. Finally, we are making use of Open Geospatial Consortium (OGC) Sensor Web Enablement (SWE) suite of

standards and some Web 2.0 capabilities to leverage emerging technologies and standards.

This research will demonstrate and validate a path for rapid, low cost sensor integration, which is not tied to a particular system, and thus be able to absorb new assets in an easily evolvable, coordinated manner. This in turn will help to facilitate the United States contribution to the Global Earth Observation System of Systems (GEOSS), as agreed by the U.S. and 60 other countries at the third Earth Observation Summit held in February of 2005.

Keywords—Sensor Webs; interoperability; on-demand science, OGC, GEOSS, Web 2.0

I. INTRODUCTION

A sensor web is a set of disparate sensors tied together with a communications fabric that are controlled in such a way as to form a cohesive whole. Figure 1 depicts our vision for a user-centric sensor web architecture that enables the user to request a feature, such as a wild fire, and receive a set of feasible

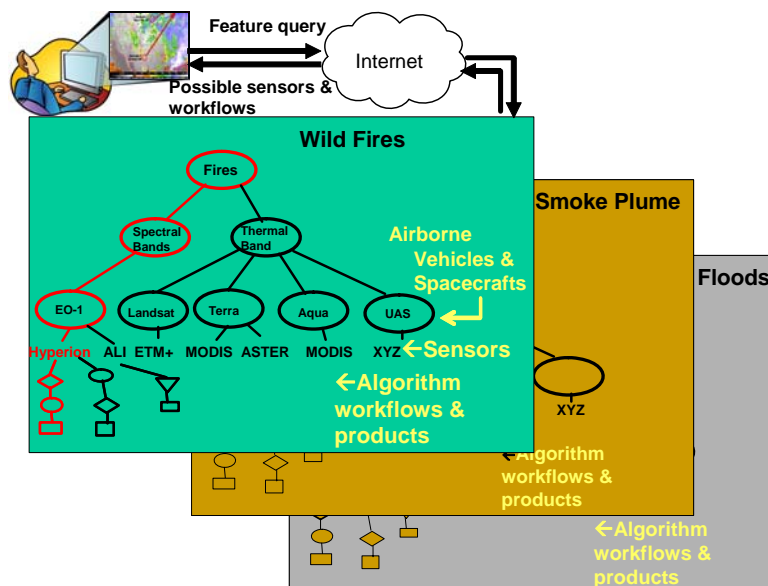


Figure 1 An ontology translates feature requests by user into sensors and workflows that can produce the desired science product

automatic workflows which can trigger selected sensors, algorithms and data delivery mechanisms to create the necessary science products. These science products are customized, assembled and delivered just-in-time. The key capability is an ontology, which can translate a feature into sets of sensors and workflows. Also, note that in figure 1, one of the branches of the tree is highlighted in red. This represents one possible workflow. So, there must also be a decision support tool to assist in picking which of the possible workflows is best. For our effort, we are experimenting with various methods to implement these capabilities.

Note that this vision for a sensor web can enable the GEOSS vision. In the GEOSS agreement, many nations want to share their diverse set of sensor assets and be able to easily mix and match the various sensors that will be available into a temporary set of cohesive sensors to deliver a science product. The tools being developed and integrated into our sensor web will perform these functions.

II. OPERATIONS SCENARIO

Our original sensor web experiments began with the EO-1 fire sensor web experiment that was conducted in August 2003 [1]. In this experiment, the MODIS instrument on the Terra spacecraft was used to survey major national wild fires as cataloged by the National Interagency Fire Center (NIFC) and then autonomously triggered a high resolution EO-1 image of the specified wild fire using a latitude/longitude of the hot spot pixels located and identified by the MODIS instrument. Later experiments included a volcano sensor web experiment [2] in which various autonomous triggers could invoke EO-1 high-resolution images, which included MODIS, insitu sensors and even triggers from science processing occurring onboard EO-1, such as the detection of hot pixels. There were also additional experiments with floods, ice and dust.

The scenario that we are developing for the summer 2007 is depicted in Figure 2. It is an expansion of our first wild fire

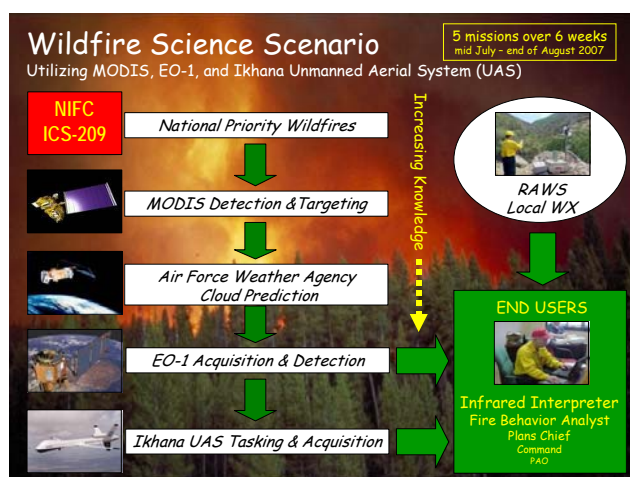


Figure 2 Target Wild Fire experiment with OGC standards and Web 2.0 capabilities

sensor web experiment. For this case, we are adding Open Geospatial Consortium (OGC) Sensor Web Enablement (SWE)

suite of standard services and some Web 2.0 capabilities. The key Web 2.0 capabilities that we plan to implement in our demonstrations are Really Simple Syndication (RSS), a method to publish frequently updated digital content and OpenID 2.0, an open, decentralized, free framework for user-centric digital identification. We may also experiment with geoRSS, which is Geographically Encoded Objects for RSS feeds in a news feed format.

III. MORE ON WEB 2.0 AND OGC SWE STANDARDS INTEGRATION

The implementation of GEOSS will be influenced by the emergence of Web 2.0 and OGC SWE standards. These are not independent activities in that Web 2.0 capabilities will be used to implement some of the OGC SWE standards. In fact, that is one of the key goals of our activity.

Web 2.0 is commonly understood as a transition of websites from isolated information silos to sources of content and functionality, thus becoming computing platforms serving web applications to end-users. It is also a social phenomenon embracing an approach to generating and distributing Web content itself, characterized by open communication, decentralization of authority, freedom to share and re-use, and "the market as a conversation". It is also characterized by enhanced organization and categorization of content, emphasizing deep linking. Finally, Web 2.0 is characterized by a rise in the economic value of the Web, which in the science world, translates to more cost-effective and responsive science products. Earlier users of the phrase "Web 2.0" employed it as a synonym for "Semantic Web", and the two concepts do complement each other.¹

The OGC SWE standards that we are using enable the following capabilities:

- Discovery
- Standard data access
- Standard tasking
- Standard alerts

In particular we are using the following OGC SWE services:

- Sensor Planning Service (SPS) – is a standard web service interface for requesting sensor acquisitions and observations. This is an intermediary interface between a user and a sensor management system.
- Sensor Alert Service (SAS) – is a standard web service interface for publishing and subscribing to alerts from various sensors.
- Sensor Observation Service (SOS) – is a standard web service interface for requesting, subsets of data produced by selected sensors.

We are also using additional OGC standard services as follows:

¹ Material from this paragraph was mainly taken from Wikipedia article on Web 2.0.

- Web Feature Service (WFS) - is a standard web service to allow requests for geographical features across the Internet using platform-independent calls.
- Web Processing Service (WPS) - is a standard web service that takes a defined set of geospatially referenced inputs, applies a specific calculation, defined by its owner, and produces a defined set of outputs.
- Web Coverage Service (WCS) - is a standard web service for exchanging geospatial data. WCS provides available data together with their detailed descriptions; allows complex queries against these data; and returns data with its original semantics (instead of pictures), which can be interpreted, extrapolated, etc.
- Web Map Services (WMS) - is a standard web service, which produces a digital image file and is often used to display data produced by a WCS on a map.
- Web Coordinate Transformation Service (WCTS) - is a web service used to transform geographically encoded data from one frame of reference to another.

Our demonstrations and experiments will use the above-mentioned capabilities and services for as many sensor assets as we are able to integrate into our experiments. Our primary sensors are the Advance Land Imager (ALI), a multispectral imager, and the Hyperion, a hyperspectral imager, on EO-1, as depicted in Figure 2. We have the most control over the interfaces to this satellite and its sensor since the primary author is also the EO-1 mission manager. For other sensors, we are collaborating with other groups and therefore are often limited in how much of the above capabilities we can implement.

IV. REFERENCE SENSOR WEB ARCHITECTURE

Figure 3 depicts our reference sensor web architecture.

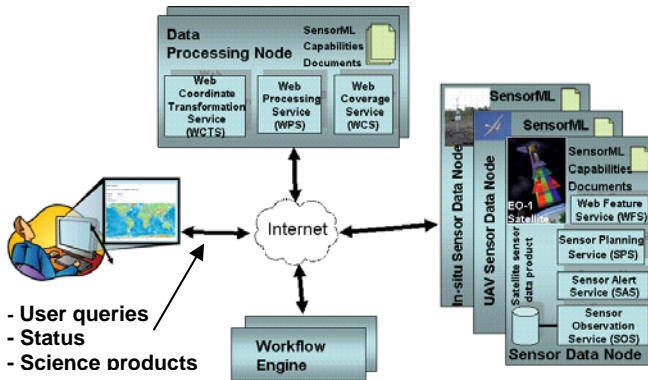


Figure 3 Vision for a user-centric sensor web architecture

Note that in this architecture, sensors are encapsulated as sensor data nodes with Sensor Markup Language (SensorML) web accessible documents that are XML-based descriptions of

the capabilities of the sensor. The capabilities may include location, resolution, spectral bands, swath and how to task the sensor. Furthermore, data processing algorithms are encapsulated as data processing nodes with SensorML or similar web accessible documents that describe algorithm functions. These descriptions may include inputs, outputs, methods employed by the algorithm and how to invoke the algorithm for user data. In both cases, the web accessible documents are created so that information about the sensors and algorithms can be discovered over the Internet and provide information on to how to access the sensors and algorithms. The user can then assemble sensor data and selected algorithms into a customized workflow or service chain in an automated fashion. This includes automatic electronic delivery of data products to the users' computer desktop, thus enabling on-demand science products.

Figure 4 represents the various ways the user may interact with the sensors and workflows. The most desirable interface would be the right most arrow in which the user intent is automatically translated into the appropriate sensor and

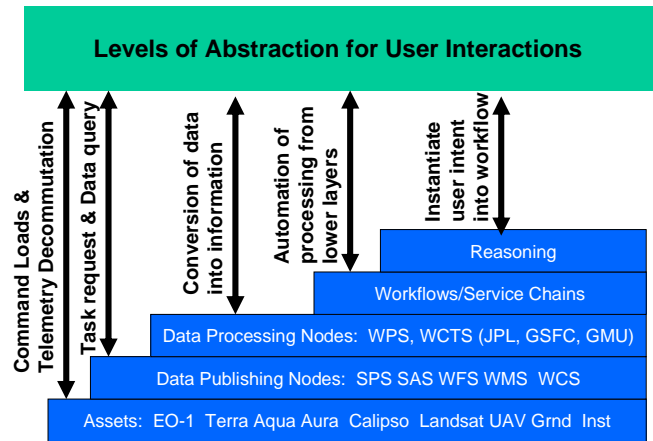


Figure 4 Levels of abstraction for user interactions going from left or right on the arrows. The user would like to use the right most arrow since that is the easiest interface.

workflow. Note that the various sensors, data nodes, data processing nodes and workflows may exist in distributed locations. The job of the workflow box and the reasoning function is to bring all the required resources together into a single functional flow.

V. DETAILED OPERATIONS SCENARIO

Figure 5 depicts our first concrete workflow using only EO-1 and the various OGC compliant services that we are creating. Note that there are two parallel workflows. The first is to invoke one of the onboard classifiers to provide a quick but rough indication as to where the fire is located. The thermal summary that is rapidly downlinked, is a file containing shapes produced by the thermal classifier indicating hot spots, but the shapes are not geolocated. This gives the user a rough indication of where the fire is located. The other workflow involves the full image and uses classifiers on the ground. This

image is geolocated; however the full processing chain may take a day or more to process and deliver to the user.

Follow-on efforts this summer will involve building similar interfaces and workflows for the other assets mentioned earlier in this paper such as MODIS, ASTER and the Ikhana UAS. Also, will be integrating OpenID 2.0 at minimum into eo1.geoblili.com and if possible into other components. We plan to use Really Simple Syndication (RSS) as the means to enable our SAS capability. Also through our collaborations we plan to explore different methods to performing discovery and building automatic workflows.

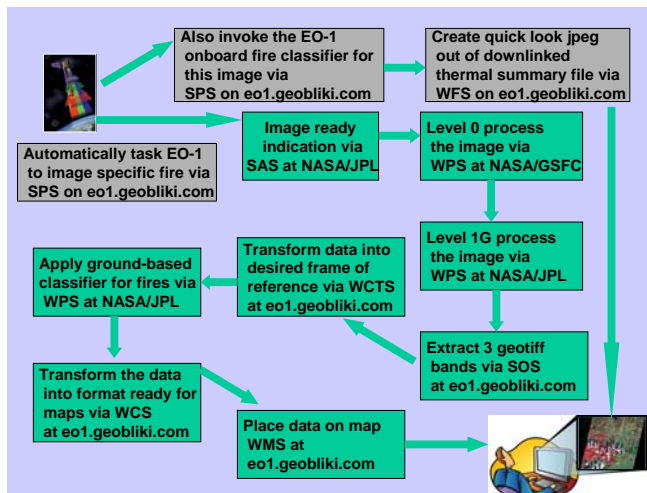


Figure 5 The first wild fire workflow using just the EO-1 satellite

VI. PARTNERS

We are collaborating with the U.S. Forest Service and the Ames Research Center (ARC) to implement this demonstration, which will include the National Interagency Fire Center (NIFC), Air Force Weather Agency (AFWA), Draper Labs, Terra, Aqua, EO-1, the Ikhana Unmanned Aerial System (UAS) and Remote Automated Weather Stations (RAWS).

Additional details on the collaborators and other collaborators and their related work not in figure 2 are as follows:

- a. NASA Advance Information Systems Technology (AIST) award - Dynamically Linking Sensor Webs with Earth System Models: Principle Investigator (PI)- Liping Di/George Mason Univ., Greenbelt, MD
 - Task involves methods to discover science products and invoke algorithm workflows automatically
- b. NASA AIST award - Increasing Technology Readiness Level (TRL) of SensorML - PI-Mike Botts/Univ. of Alabama, Huntsville, AL

-Use SensorML for discovery and invoking algorithm workflows

- c. NASA AIST award – Sensor-Analysis-Model Interoperability - PI – Stefan Falke/Northrop-Grumman/Washington Univ. in St. Louis, MO
 - Standard model interfaces to drive sensor webs
- d. NASA AIST award – Sensor Web Dynamic Replanning: PI - Steve Kolitz/Draper Labs, Cambridge, MA
 - Decision support systems for sensor webs
 - Cloud screening for optimized tasking of satellite assets
- e. NASA AIST award - Using Intelligent Agents to Form a Sensor Web for Autonomous Operations: PI- K. Witt/WVHTF, Fairmont, WV
 - Help implement SensorML use to describe sensor capabilities for discovery
- f. NASA AIST award -Volcano Sensor Web: PI- Ashley Davies/NASA-JPL, Pasadena, CA
 - Detect and image volcanoes autonomously with EO-1
- g. Wildfire Research and Applications Partnership (WRAP) – V. Ambrosia-NASA-ARC and E. Hinkley/US Forest Service
 - Unmanned Aerial System (UAS) to augment sensor web
- h. Remote Automated Weather Stations (RAWS) data access – J. Horel, Univ. of Utah, Salt lake City, UT
 - Data access to RAWS
- i. ASTER - PI – M. Abrams/JPL, Pasadena, CA
 - Possible ASTER data access for sensor web demonstration

VII. CONCLUSION

The sensor web experiments being conducted under the NASA AIST task described in this paper lay the groundwork for capabilities required to enable GEOSS. The real applications that are being built will add additional credibility. We have isolated the capabilities of discovery and automatic workflows as key capabilities to make future GEOSS architectures cost effective.

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